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**AIAA 99-0819**

# **The Future of Hypersonic Wind Tunnels**

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**19991130 086**

**37th AIAA Aerospace Sciences  
Meeting & Exhibit**

**January 11-14, 1999 / Reno, NV**

# The Future of Hypersonic Wind Tunnels

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## Abstract

Aerospace plays a key role in the United States' economy and national security. The recent Gulf War is a good example of the importance of aerospace systems. In the commercial sector, air travel continues to thrive. Aerospace technology and systems development capabilities existing in the United States today can be linked to the significant infrastructure investments between 1945 to 1975. These investments were made not only for subsonic and supersonic research and development, but also for a test and evaluation (T&E) infrastructure. This infrastructure consisted of wind tunnels, propulsion test cells, and trained personnel to operate them. These facilities have been crucial for reducing technical risk during the system development process. By identifying design problems early in the development cycle, huge costs for redesign or fixes have been avoided. Aerospace, no doubt, has played a significant role in the United States becoming a "Super Power."

Aerospace systems development will continue to play a key role in the 21<sup>st</sup> century. The desire to get to a target quicker (global engagement) and take payloads into space cheaper is now driving us towards the need for hypersonic systems. These hypersonic systems, like the subsonic and supersonic systems of the present, will require wind tunnels and propulsion test facilities to reduce development risk. The technical and financial challenges in acquiring and sustaining future hypersonic T&E facilities are impacted by the current environment of downsizing, partnering, and privatizing. This paper will address the system requirements that are driving us towards hypersonic systems and the issues associated with building hypersonic wind tunnels or aeropropulsion T&E facilities suitable for system development.

## Introduction

For more than 30 years, this country has invested in several programs attempting to develop air-breathing hypersonic vehicles. However, in general these programs have been research efforts and technology demonstrations. The most ambitious program was the DoD/NASA National Aerospace Plane (NASP) program of the 1980's. The goal of this program was to achieve orbital flight with a single stage for airplane-like operations.<sup>1</sup> This was the most prominent hypersonic program in this country during that time. Although the program produced a number of significant technological advances, the NASP never reached fruition in part due to the lack of adequate tools. However, we learned enough from these previous hypersonic programs that many feel that we can now develop a small hypersonic vehicle powered by an air-breathing propulsion system for Mach 8 flight. Some even suggest that Mach 10 is attainable in the near future.

At least two programs are developing Mach 8 missile-size scramjet systems under DoD sponsorship. These programs are the AFRL Hypersonic Technology Program (HyTech)<sup>2</sup> and the DARPA Affordable Rapid Response Missile Demonstrator (ARRMD).<sup>3</sup> Both programs are aimed at developing a scramjet engine that burns hydrocarbon fuel<sup>4</sup> for flight line-type operations. NASA is also developing scramjet propulsion systems, but that agency is concentrating its efforts on hydrogen-fueled systems. The government and industry are also involved in developing space lift systems, and air-breathing propulsion may play a role in some of these systems.

These hypersonic propulsion technology programs and the need for fast response weapon sys-

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tems to kill time-critical targets place a new, stronger emphasis on hypersonics. In addition, several national studies<sup>5-9</sup> provide credibility for developing adequate ground testing capabilities to mitigate the risk in developing hypersonic systems.

Unfortunately, current ground test capabilities are not available for developing air-breathing propulsion systems that will fly at Mach 8 or greater. This paper will describe a few of the systems that will challenge our ability to adequately develop hypersonic air-breathing systems with the existing T&E infrastructure. The paper will discuss existing ground test capabilities, gaps in the existing T&E infrastructure, and some of the ongoing efforts to mitigate these shortfalls. In addition, the paper will discuss some issues associated with building hypersonic wind tunnels in the current environment of reducing T&E infrastructure by about 25 percent.

### Hypersonic System Requirements

A number of futuristic systems have been identified in the literature, such as the Air Force's *New World Vista*s study.<sup>7</sup> These are manned and unmanned hypersonic vehicles envisioned to satisfy a number of missions against various potential threats. A hypersonic air-breathing missile is discussed in the AGARD report, Aerospace Study 2020.<sup>10</sup> A recent National Research Council report, *Review and Evaluation of the Air Force Hypersonic Technology Program*, infers that the Air Force would like to have an air-breathing Mach 8 missile by the year 2015.<sup>9</sup> This report also envisions a number of other futuristic hypersonic technology applications beyond the Mach 8 missile, such as access to space. Rocket propulsion is currently the only logical means of providing space lift;<sup>11</sup> however, hypersonic air-breathing propulsion still holds an interest for these systems in the future.

These futuristic concepts are visionary ideas with research being done only for demonstrating the technology. None of these concepts are real system development programs with sufficient funding to produce a weapon system. The hypersonic air-breathing propulsion missile is the only potential concept that might evolve into a real weapon devel-

opment program in the near term. However, in planning for a new wind tunnel that takes 10 to 20 years to build, all the potential futures must be considered in its development. Figure 1 shows that major facility acquisition time at the Arnold Engineering Development Center (AEDC) is very long. This figure shows that a new wind tunnel takes an average of 11 years to build. Therefore, the facility acquisition must precede a weapon development program by several years, prior to Phase 0. Hence, the futuristic systems that are only in the minds of the visionaries must also be included in the facility development plan.

Once the systems are defined, the T&E capabilities required to support their development can be defined. This is done by performing a gap analysis where the existing capabilities are compared with the T&E capabilities required. The process is shown in Fig. 2. In this process, the system requirements information is gathered from studies, long-range planning documents, and mission need statements. The system requirements, along with the mission information, will identify the types of

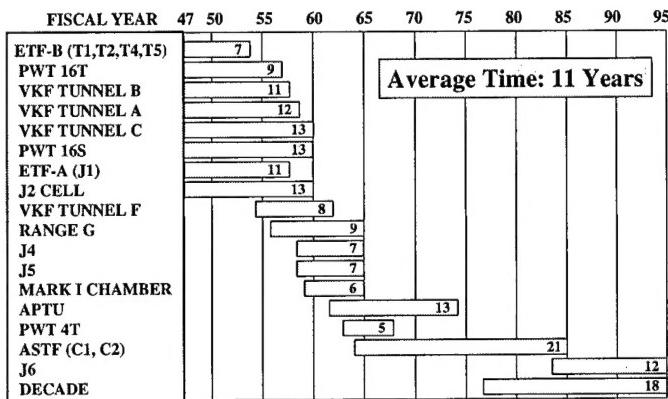


Fig. 1. Major AEDC test facility acquisition time.

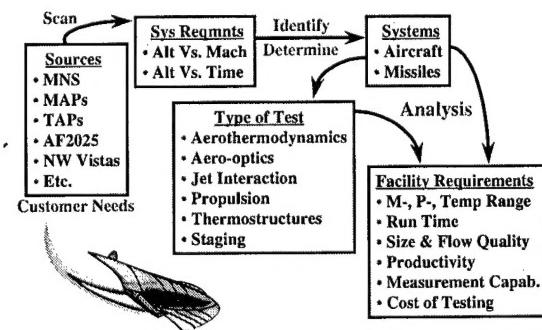


Fig. 2. Process to determine test facility requirements.

testing that will be required. An analysis of the system requirements and the types of testing required to evaluate the system will lead to identification of the test parameters that must be duplicated on the ground. These required test parameters (e.g., Mach number, thermodynamics, flow path size, facility run time, etc.) can then be compared to the existing T&E capabilities to identify the gap or shortfall.

The systems will be divided into three types or classes of vehicles. They are tactical missiles,<sup>9,10</sup> interdiction/reconnaissance vehicles (manned and unmanned), and fully reusable space lift vehicles (also manned and unmanned).<sup>11</sup>

Typical tactical missile concepts are the ARRMD and HyTech. Of course, HyTech is not a flying system. However, this technology would provide the basis for a future tactical missile. These missile concepts are for a system to be launched from an aircraft and cruise at Mach 6-8. The weight of these systems must be in the weight range for bomber rotary launchers and fighter aircraft undercarriage installations. These would be fixed-geometry scramjet propulsion systems with endothermic hydrocarbon fuels. The range of these missiles is from approximately 800 to 1,200 nm.<sup>9</sup>

Future tactical missile systems may include larger air-launched guided vehicles. These systems may fly at Mach 10-12 and would have a range similar to the Mach 8 systems. A typical tactical missile mission profile is shown in Fig. 3.<sup>9</sup> The smaller missile system would likely be used on time-critical targets, whereas the larger missile system may have a similar mission profile, but for hardened targets.

Interdiction/reconnaissance-type vehicles are discussed in *New World Vistas*.<sup>7</sup> These systems

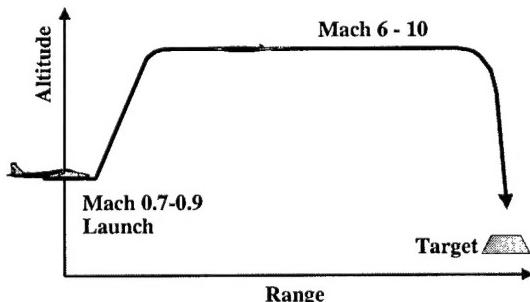


Fig. 3. Typical hypersonic missile mission profile.

may be manned or unmanned and cruise at Mach 4-10. The systems that would cruise at the lower Mach numbers will likely be powered by air-breathing engines burning conventional JP fuels (endothermic hydrocarbon). However, liquid hydrogen fuels will likely power the systems that cruise at Mach 10.

The X-30 is a space launch vehicle concept (Fig. 4) suitable for assessing test facility requirements. This single-stage-to-orbit (SSTO) concept and other follow-on derivatives continue to be evaluated. These systems are powered by very complicated propulsion systems using rockets, ramjets, and scramjets. A number of simpler two-stage-to-orbit (TSTO) launch vehicles have also been studied over the years. However, the role of air-breathing propulsion systems for space launch is not clear. Rocket propulsion systems will likely continue to be the power of choice for these systems for the next 10-20 years. However, the test facility requirements for a future hypersonic wind tunnel must include these systems, since the acquisition time is very long.

The United States is not the only country interested in developing hypersonic vehicles. Hypersonic system development and research programs are also in progress in Japan, France, Germany, the United Kingdom, and Russia. Many of these countries are investing in their hypersonic test capabilities to support the programs. Therefore, the United States must invest in technology and ground test infrastructure to remain a world leader in hypersonics.

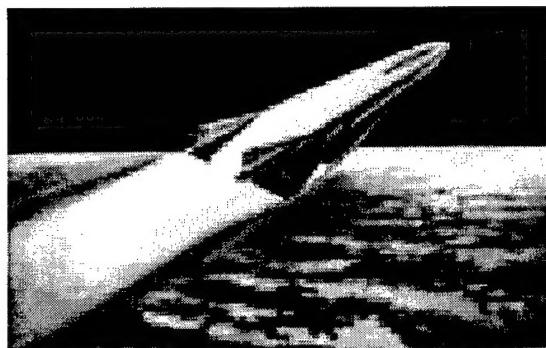


Fig. 4. Space launch vehicle concepts (X-30).

### Hypersonic Test Requirements

The components of a typical assymetric hypersonic aeropropulsion system are shown in Fig. 5.

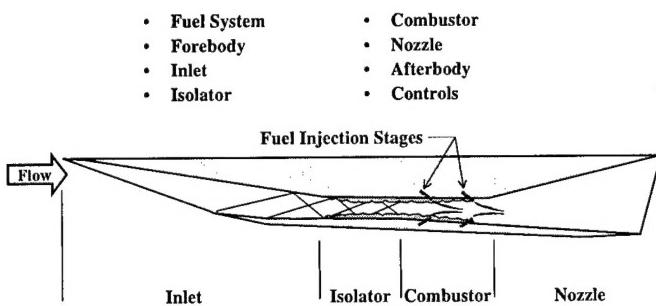


Fig. 5. Hypersonic aeropropulsion system components.

Development of the aeropropulsion system is accomplished by testing the individual components, multiple components, and the integrated system. Several different facilities are typically used in the development of these individual components. For example, the inlet may be tested in wind tunnels where true temperature conditions are not provided. However, true temperature conditions will be required for developing the combustor and associated combustion system (e.g., fuel injection stages). Aerothermodynamic flight simulation capabilities (encompassing aerodynamics, aero-heating, fluid dynamics, and physical processes)<sup>12</sup> are essential for development of advanced hypersonic systems. A developmental hypersonic ground test capability must be able to evaluate the integrated aeropropulsion system performance, operability, and durability. This is the most demanding requirement for a wind tunnel.

Aeropropulsion system performance entails measuring/assessing:

- Net thrust, specific thrust, and specific impulse
- Net lift and moments
- Mass capture
- Thermal balance

Aeropropulsion system operability entails measuring/assessing:

- Off-design operation
- Inlet starts, unstarts, and instabilities
- Lightoff and blowout
- Combustion stability and control
- Fuel control

- Inlet distortion (steady state & transient)
- Flight transients (maneuvers/atmospheric)
- Nozzle instabilities
- Thermal management

Aeropropulsion system durability entails measuring/assessing:

- Temperature limits
- Thermal stresses and gradients
- Acoustic loads
- Mechanical stresses
- Joints, fittings, attachments, etc.
- Laminated material layers

The aeropropulsion test requirements are shown in Fig. 6. This chart shows the types of tests required and the needed capability to do hypersonic aeropropulsion testing on the forecasted weapon systems/programs. The near term is a 5- to 7-yr time frame. Mid term is ten years following the near term. Long term is for a time frame of 17+ years. These types of tests are usually done in propulsion cells that simulate true flight conditions (Mach number, pressure, and temperature) and are typically conducted on a full-scale model or even flight capable equipment. Typical measurements are thrust, engine internal pressures (dynamic and static), and temperatures. The stressing requirements are size, run time of the facilities, high Mach numbers and the quality of the flow (in the process of providing the correct conditions in the test cell, sometimes the air properties are changed where the propulsion simulation is not valid).

Types of Tests		Needed Capability		
PARAMETER	TERM	NEAR	MID	FAR
MACH NUMBER	≤ 8.0	≤ 10.0	≤ 16.0	
ALTITUDE (ft)	70-120K	70-140K		LEO
FACILITY SIZE	≥ 15 ft L 50% Blkg	≥ 15 ft L 50% Blkg	≥ 15 ft L 50% Blkg	
RUN TIME	5-10 min	5-10 min	7 minutes	
FLOW QUALITY	✓	✓	✓	
PRODUCTIVITY	✓	✓	✓	

Fig. 6. Aeropropulsion test requirements.

The aeropropulsion test capability gaps are shown in Fig. 7. AEDC's hypersonic aeropropulsion capability consists of the Aerodynamic and Propulsion Test Unit (APTU) with a planned upgrade. This facility is unique because of its large size, long run time, and fuel handling capability. It has supported past hypersonic propulsion research programs and the development of weapon systems that used its structures/structural dynamics capability. AEDC works closely with NASA and their counterpart facilities under a recent memorandum of agreement (MOA) to cooperate on technology, investment planning, and process standardization. There are serious gaps in the capability to meet hypersonic aeropropulsion test requirements with the current national capabilities. For tactical missile systems that fly up to Mach 8 the APTU needs upgrading to provide higher Mach number and longer run times. There is no capability to test aircraft scale engines at hypersonic Mach numbers. Also, there is no capability to test missile or aircraft scale engines at Mach numbers greater than 8. Gaps in test techniques for endothermic fuels and total system assessment exist, a sign that it is not able to meet the needs of the development community.

The hypersonic aerothermodynamic test requirements are shown in Fig. 8. This figure shows the types of tests required and the needed capability to do hypersonic aerothermodynamic testing on the forecasted weapon systems/programs. These types of tests are usually done in perfect/real gas wind tunnels that simulate the correct Mach number and Reynolds number/pressure altitude, but do not simulate the true temperature. Typical measurements are force and moment, pressure (dynamic and static), heat transfer, vehicle motion, flow-field characteristics, etc. The tests are usually conducted on scale models of the weapon system or subsystem.

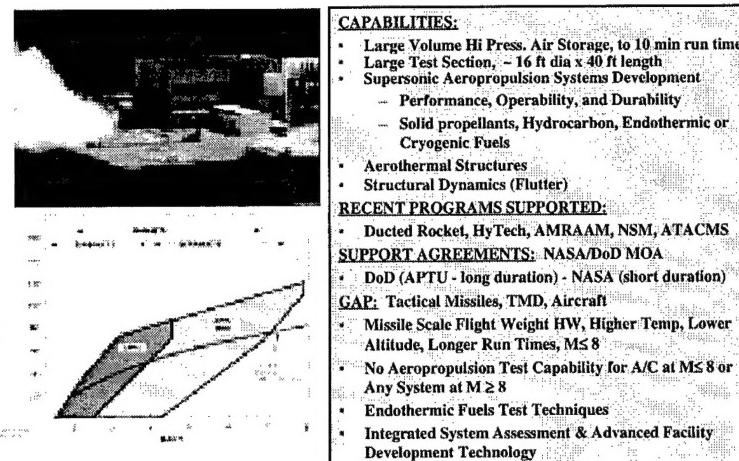


Fig. 7. Aeropropulsion test capability/gap.

Types of Test					
	Aerodynamic/Stability & Control	Powered Effects	Inlet/Flowpath performance	Aero-Optics Performance	Aero/thermal Heat Transfer
	• Aerodynamic/Stability & Control	• Powered Effects	• Inlet/Flowpath performance	• Aero-Optics Performance	• Aero/thermal Heat Transfer
	• Multiple Body Separations (CTS)	• Jet Interaction Controls			

Needed Capability					
PARAMETER	TERM	NEAR	MID	FAR	
MACH NUMBER		≤ 16.0	≤ 16.0	≥ 16.0	
FACILITY SIZE		≥ 3 ft D	≥ 3 ft D	≥ 15 ft D	
RUN TIME		Cont.	Cont.	Cont.	
FLOW QUALITY		✓	✓	✓	
PRODUCTIVITY		✓	✓	✓	

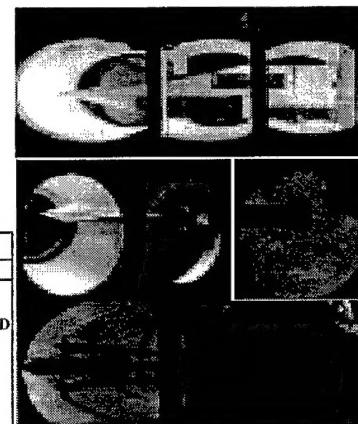


Fig. 8. Aerothermodynamic test requirements.

The hypersonic aerothermodynamic test capability gaps are shown in Fig. 9. AEDC's aerothermodynamic capability consists of hypersonic wind tunnels B, C, and 9 (located in White Oak, MD).

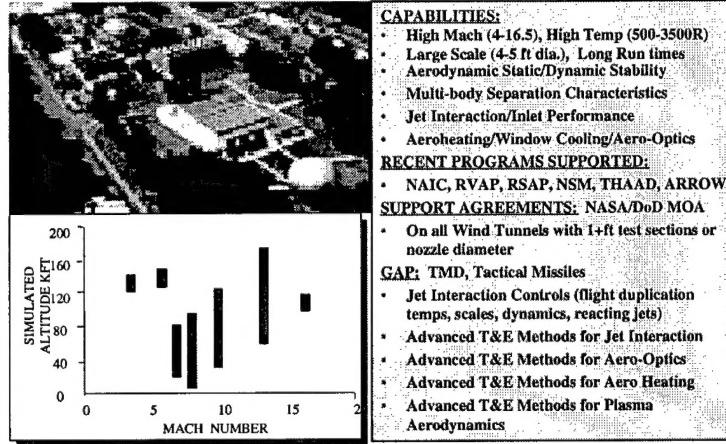


Fig. 9. Aerothermodynamic test capability/gap.

These facilities are unique for their hypersonic test capability due to their size, flow quality, and long run times. They have supported the development of all the nation's previous hypersonic systems and continue to be used sporadically for current developments. AEDC works closely with NASA and their counterpart facilities under a recent MOA to cooperate on technology, investment planning, and process standardization. The significant gaps in capability to meet the forecasted system/program test requirements are supporting Ballistic Missile Defense Organization (BMDO) with their jet interaction and aerodynamics testing and pursuing advanced T&E methods.

Impact/lethality test requirements are shown in Fig. 10. This figure shows the types of tests required and the needed capability to do hypersonic impact/lethality testing on the forecasted weapon systems/programs. These types of tests are usually done in aeroballistic ranges where the projectiles are launched down a closed-in range in free flight to impact targets. These tests simulate the correct environmental conditions and the correct projectile velocity. The projectile is usually a scale model version of the weapon system with attempts to match structural characteristics. Stressing requirements are for larger projectiles to be launched with low launch loads and at higher velocities. These types of test facilities also provide capabilities that do not require impact, such as measuring wake physics (signatures) of the projectile while in free flight and capturing the model at the end of the test without destruction.

The impact/lethality test capability gaps are shown in Fig. 11. AEDC's impact/lethality capability is its 1000-ft aeroballistic range G. This facility is unique because of its large bore diameter, low launch loads, and high launch velocities. It has supported many hypersonic impact weapons developments in the past. AEDC works closely with NASA and their counterpart facilities under a recent MOA to cooperate on technology, investment planning, and process standardization. The gaps in capability to meet the forecasted test

requirements are in larger scale projectiles at higher velocities. These requirements could be met with newer larger launchers in G Range, and with development of the counter-fire capability in which the relative velocity of two approaching projectiles (as opposed to one approaching and one stationary) is used to achieve higher velocity requirements. Also, technology in model design, on-board data systems, and impact diagnostics is needed.

Needed Capability				
PARAMETER	TERM	NEAR	MID	FAR
VELOCITY (k/s)		7	15	15
MODEL DIA (in)		8	12	16
LAUNCH LOADS (g)		80K	50K	20K
PITCH ANGLE		30 deg	30 deg	45 deg
PRODUCTIVITY		✓	✓	✓

Types of Tests	
Impact	- System Performance - Code Validation
Lethality Assessment	- Kill Probability - Damage Validation
Survivability	- Damage Assessment - Code Validation
Weather Erosion	- Rain, Snow, Dust
Wake Physics	- Signatures

Fig. 10. Impact/lethality test requirements.

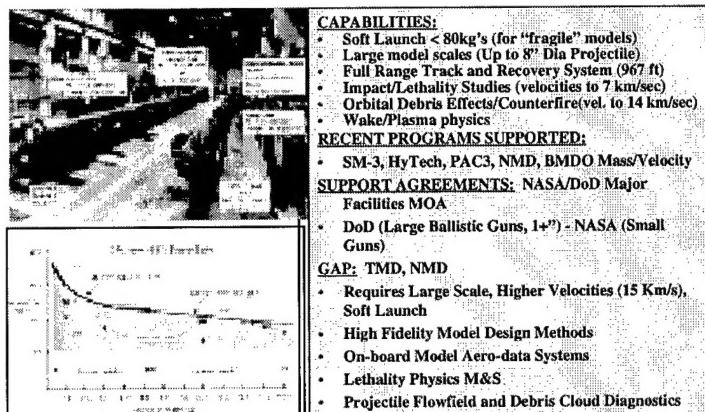


Fig. 11. Impact/lethality test capability/gap.

Materials/structures test requirements are shown in Fig. 12. This figure shows the types of tests required and the needed capability to do hypersonic materials/structures testing on the forecasted weapon systems/programs. These types of tests are usually done in arc heated facilities that simulate the correct temperature and pressure, but may miss the Mach number. The test article is usually a sample of the weapon system materials/structures that would be encountering the severe thermal environment of flight. Stressing requirements are for longer run times at higher pressures and temperatures. These test requirements are for

flow facilities such as the ones located at AEDC. Other test requirements for materials/structures evaluation can be met by non-flowing facilities where high-power lamps apply the heat load, and the pressure load is applied by hydraulic jacks. These types of facilities are located at other sites.

The materials/structures test capability gaps are shown in Fig. 13. AEDC's materials/structures capability consists of the arc heated facilities H1, H2, and H3. These facilities are unique because of their high-pressure and high enthalpy operation. They have supported many hypersonic developments in the past. AEDC works closely with NASA and their counterpart facilities under a recent MOA to cooperate on technology, investment planning, and process standardization. The gaps in capability to meet the forecasted test requirements are in test article size, higher pressures, and longer run times. Continued arc heater research into higher pressure/enthalpy operations is needed. Test technologies in structures testing are also needed.

A summary of the existing hypersonic test capabilities is shown in Fig. 14. This figure summarizes the capability shortfalls (gaps) that have been identified by comparing the forecasted future test requirements with the existing test capability. Based upon the schedules of the forecasted systems/programs and their operating envelopes, some of these shortfalls present critical deficiencies. For instance, the need to conduct aeropropulsion testing, aero-optics testing, and jet interaction testing at Mach numbers lower than 8 needs immediate attention. The other shortfalls are noted for higher Mach number test requirements, but are not as pressing from a schedule perspective. However, the approach to solving some of these shortfalls may require such large advances in the state of the art for facility design, construction, and operation that research in the near term is required to be ready to meet the test needs in the far term.

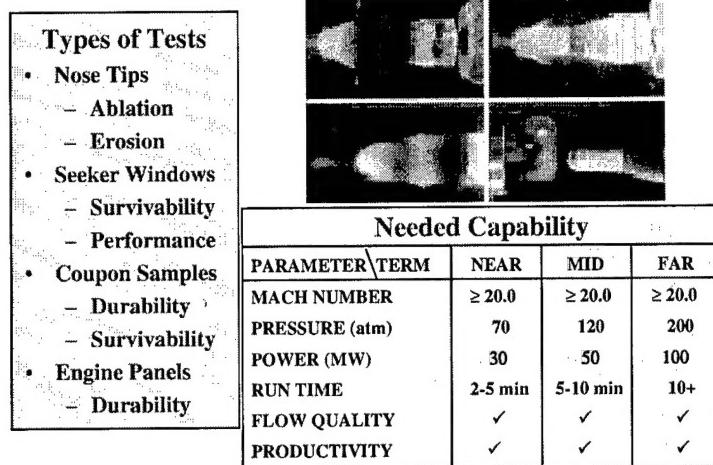


Fig. 12. Materials/structures test requirements.

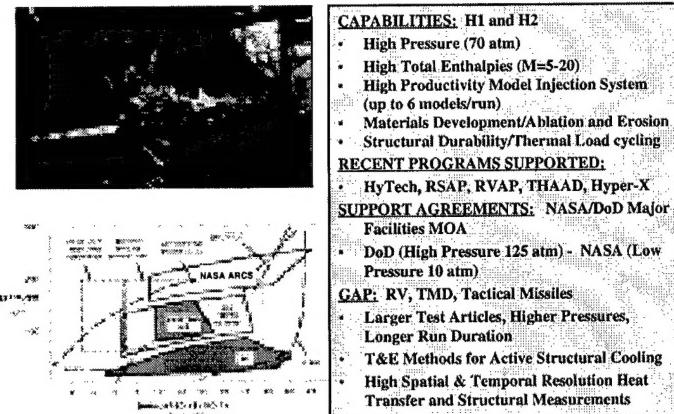


Fig. 13. Materials/structures test capability/gap.

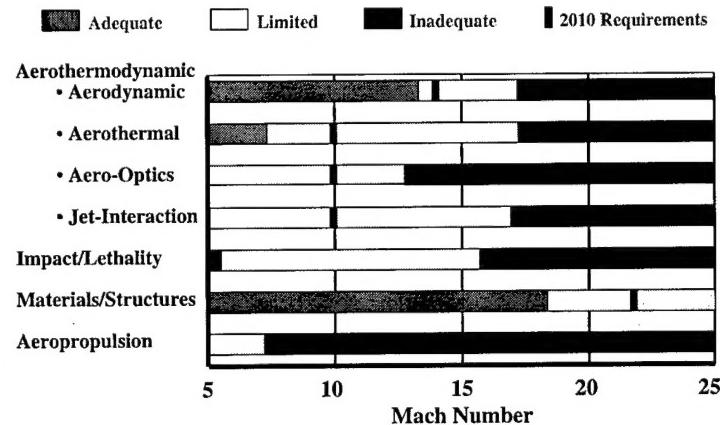


Fig. 14. Summary of existing hypersonic test capabilities.

### Hypersonic Test Facility Planning

The desired hypersonic T&E capability future must consider system requirements, existing capabilities, and the state of the art of facility technology. Current state-of-the-art facility technology

cannot provide adequate design information for a ground T&E capability that resolves all the current shortfalls. Therefore, integrated T&E will play a greater role in hypersonics than in the lower speed regimes. Currently, hypersonic system developments must depend much more on flight testing<sup>13</sup> than developments in the lower speed regimes. However, since flight testing is more costly, the desired future is to increase the dependence on ground testing and modeling and simulation (Fig. 15). This figure shows qualitatively that the dependence on flight testing can be reduced by a significant amount, while maintaining a constant confidence in the system performance.

The AEDC hypersonic propulsion testing support plan is shown in Fig. 16. This is an integrated plan that connects the proposed ground test facilities to the system requirements and the system technology development. This plan shows only the potential systems out to the year 2016. The plan also identifies the ground test technology required to upgrade facilities or build new ones. Just as the system technology is essential to the system development process, so is the facility technology that provides the basis for new or upgraded facilities.

### Future Hypersonic Wind Tunnels

This paper provides current insight of the hypersonic system requirements. In the near term, we need to provide a Mach 8 missile test capability by 2010. The far term needs are less clear, but projected needs include a test capability to test space launch systems and interdiction/reconnaissance vehicles.

Tactical missiles are the most logical systems to be developed in the near term. These are the endothermic hydrocarbon-fueled systems that will cruise at Mach 8. An upgrade to the AEDC Aerodynamic and Propulsion Test Unit (APTU) will satisfy this

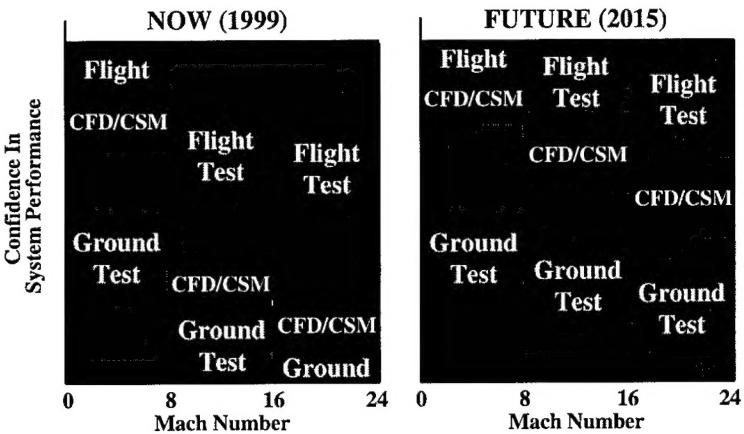


Fig. 15. Desired hypersonic T&E future: increasing dependence on ground testing and M&S.

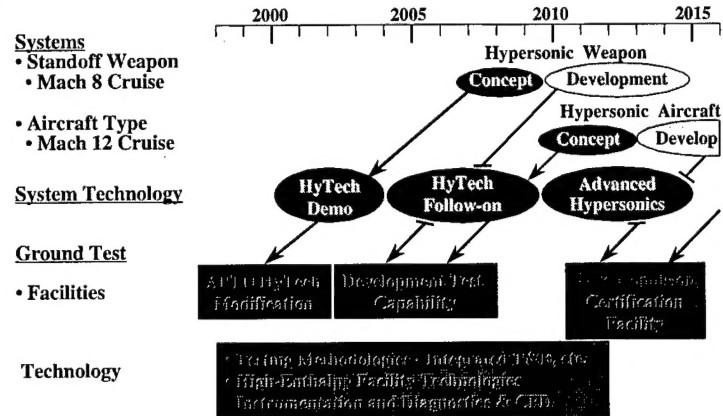
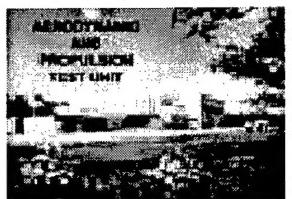


Fig. 16. USAF hypersonic propulsion testing support plan.

requirement (Fig. 17). APTU is a large size (16-ft-diam test chamber), blowdown facility with a vitiated test medium that exhausts into the atmosphere. The facility has a large high-pressure air storage capacity that provides long-duration run times. The current facility capability is limited to

#### Project Description

- Modify APTU to support Mach 2-8 Full Scale Tactical Missile Operability/Durability Testing
  - Increase Air Storage System Volume
  - Install Existing Burners in Stilling Chamber for Mach 8 Enthalpy
  - Modify Exhaust System for higher Altitude Simulation Environment
  - Design and Fabricate For Quick, Low-Cost Configuration Changes



#### Benefits / Payoff

- Fixes MAJOR Shortfall in Weapons Acquisition Process
  - T&E Facilities for Hypersonic Air Breathing Tactical Missiles at Mach 8 Nonexistent
  - Supports Air Force HyTech and FRSW, Navy HyStrike and Standard Missile, DARPA ARRM, and Others
- Reduces Development Cycle Time and Amount of Flight Test Required
  - Ground T&E Focuses Flight Test

#### Cost / Schedule

Total Funding: \$18,000,000

Fiscal Year	02	03	04	05
Requirement (\$M)	3.5	6.0	5.0	3.5

Fig. 17. Aeropropulsion test capability, M ≤ 8.

Mach 4. The proposed upgrade includes adding a Mach 8 capability with a new nozzle, additional air storage to increase facility run time to 12-15 min, and modification of the exhaust system for higher altitude simulation to approximately 110kft.

A new hypersonic wind tunnel is under consideration for the long-range system requirements (Fig. 18). This concept is being evaluated and developed by a team from Princeton, Lawrence Livermore Laboratory, Sandia Laboratory, and MSE, Inc. under AEDC management. The facility is to provide flight duplication conditions for Mach numbers up to 15. A missile-scale prototype wind tunnel will be developed initially with a clean air test medium (noninitiated), and a dynamic pressure of at least 2,000 psf. The desired run time is greater than 1 sec. This concept is a blowdown facility with an ultra high-pressure air storage system, a pre-heater (noninitiated), with energy addition downstream of the nozzle. A magnetohydrodynamic accelerator will be added downstream to further accelerate the flow. The concept is in its early stages of development, but the technology results do not show any show stoppers thus far. The proposed schedule shows the technology development to be completed by FY05 and the prototype construction to be completed by FY09 (Fig. 19).

### Test and Evaluation Models

The traditional system development T&E model (Fig. 20) will have to change for hypersonic systems. The traditional T&E development approach follows the DoD program development phases with modeling and simulation (M&S), ground testing, and flight test without much feedback or interaction between the three. The T&E and system development process shows that costs increase as system development progresses. This traditional approach will have to change because ground test facilities will not be able to evaluate hypersonic systems adequately at very high Mach numbers.

- Flight Duplication for Mach 12-15
- Missile Scale (Approximately 1.0 m)
- Clean Air,  $q = 2,000$  psf
- Run Time > 1 sec

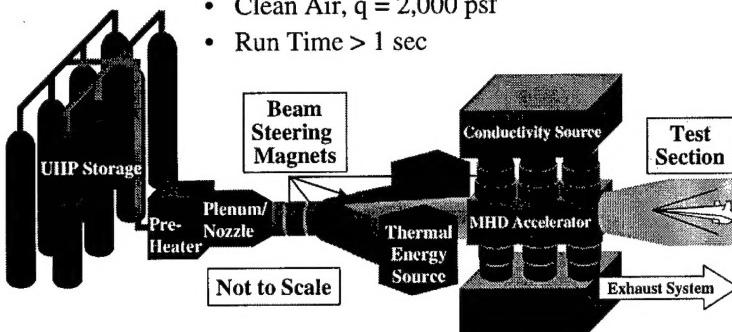


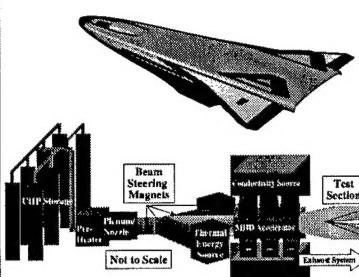
Fig. 18. Hypersonic wind tunnel concept.

#### Project Description

- Develop Prototype Facility for Flight Duplication at Mach 8-20 (Clean Air, Run Duration of Secs)
  - Specify Facility Design Based for Concept Exploration and Demonstration Phase
  - Design and Develop Prototype Facility
  - Acquire Facility Performance and Operational Data
  - Develop Design Spec for Full-Scale Facility Acquisition

#### Benefits / Payoff

- Demonstrate Facility to Overcome MAJOR Shortfalls in Advanced Weapons Acquisition Process
  - T&E Facility Integration and Demonstration Required to Support Funding Decisions
  - Supports 2nd Generation Air Force Military Space Plane Vision and Tri-Service Visionary Hypersonic Vehicles and Weapons
- Reduces System Development Risk, Cycle Time and Flight Test Requirements



#### Cost / Schedule

Total Funding: \$100,000,000

Fiscal Year	03	04	05	06	07	08	09
Requirement (\$M)	3.3	4.0	6.7	10	19	36	25

Fig. 19. Aeropropulsion test capability,  $M \geq 8$ .

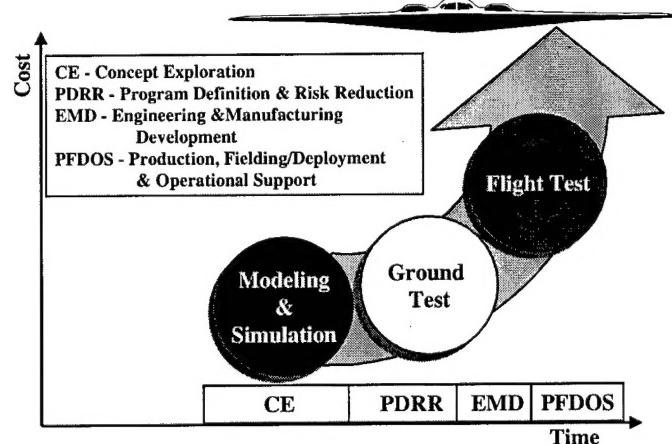


Fig. 20. Traditional system development test and evaluation model.

Integrated T&E will become more important in future system developments (Fig. 21). This new paradigm change is smart for T&E in general, but it is essential for hypersonic systems.

### Wind Tunnel Acquisition Issues

The acquisition of future hypersonic wind tunnels will be at least as difficult as other recent wind tunnel acquisition initiatives. However, in many aspects the acquisition of future hypersonic wind tunnels will be more difficult. The hypersonic test environment is much more hostile and difficult to simulate at reasonable cost. The energy requirements are much higher than those at the lower Mach regime (Fig. 22).

In addition to the technology challenges, the cost of a future hypersonic wind tunnel will likely run into the billions of dollars. Recent attempts to acquire other proposed major wind tunnels costing billions of dollars were unsuccessful. This was in spite of a coordinated national initiative with participation from government and industry.

The solution might be the approach being pursued with the new hypersonic wind tunnel (Fig. 18). This approach includes an affordable prototype missile-size wind tunnel that will support hypersonic technology programs, as well as missile development programs. This will provide credibility and advocacy for the full-scale hypersonic wind tunnel. The effort is a national initiative with participation from government, industry, and academia. In addition, the program is being managed as a system development program. This may support the advocacy for the facility and allow it to compete with other major systems.

### Summary

Studies continue to identify potential hypersonic systems that will satisfy requirements for tactical missiles, hypersonic aircraft, and space lift systems. However, without a real system, acquisition of a hypersonic wind tunnel is difficult to advocate. The challenge must be pursued with the Air Force vision in mind (Fig. 23). "We are transitioning from an air force into an air and space force on an evolutionary path to a space and air force." Hypersonics will play a major role in fulfilling this vision and we must advocate it. Hypersonic ground test facilities will be needed to support the vision and we must also advocate them. A national cooperative hypersonic test

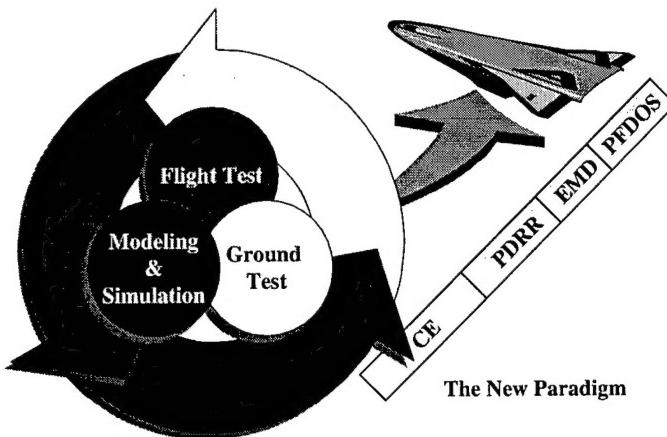


Fig. 21. Future system development model: integrated test and evaluation.

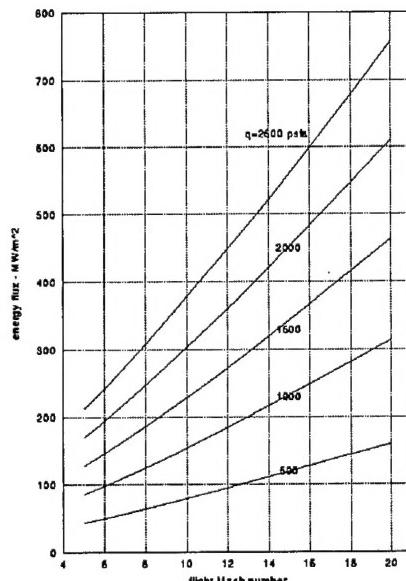
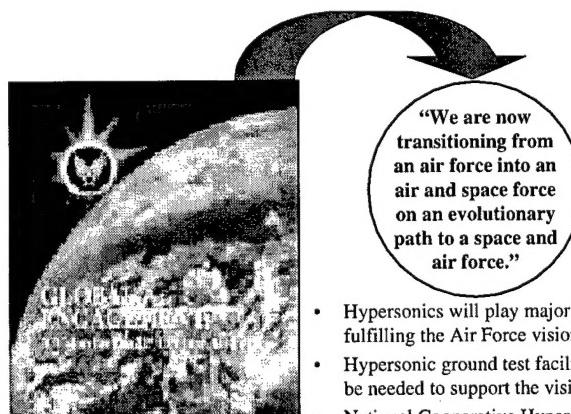


Fig. 22. Energy flux requirements.



- Hypersonics will play major role in fulfilling the Air Force vision
- Hypersonic ground test facilities will be needed to support the vision
- National Cooperative Hypersonics Test Investment Program Needed

Fig. 23. Air Force vision.

investment program will also be needed to support the advocacy.

## References

1. Chase, R. L. and Tang, M. H., "A History of the NASP Program from the Formation of the Joint Program Office to the Termination of the HySTP Scramjet Performance Demonstration Program," AIAA 95-6031, April 1995.
2. Mercier, R. A. and Ronald, T. M. F., "Hypersonic Technology (HyTech) Program Overview," AIAA 98-1566, April 1998.
3. Price, W. R., "Affordable Rapid Response Missile Demonstrator (ARRMD) Program," DARPA Solicitation #98-01-845-PRK, March 1998.
4. Reddecliff, J. and Weber, J., "Development and Demonstration of a Hydrocarbon Scramjet Propulsion System," AIAA 98-1613, April 1998.
5. *Future Aerospace Ground Test Facility Requirements*, National Academy Press, Washington, D.C., 1992.
6. *National Facilities Study*, April 1994.
7. McCall, G. H., et al., *New World Vistas*, December 1995.
8. *Air Force 2025*, Air University Press, Maxwell Air Force Base, Alabama, August 1996.
9. Seebass, A. R., *Review and Evaluation of the Air Force Hypersonic Technology Program*, National Academy Press, Washington, D.C., 1998.
10. Home, N., et al., "Aerospace 2020," AGARD-AR-360 Vol. I, April 1997.
11. Anttonen, J., "U. S. Air Force Space Operations Vehicle," AIAA 98-1568, April 1998.
12. Miller, C. G., "Aerothermodynamic Flight Simulation Capabilities for Aerospace Vehicles," AIAA 98-2600, June 98.
13. Metha, U., "Hypersonic Propulsion Flight Tests as Essential to Air-Breathing Aerospace Plane Development," AIAA 95-6156, April 1995.
14. Erdos, J. I., "On the Bridge from Hypersonic Aeropropulsion Ground Test Data to Flight Performance," AIAA 98-2494, June 1998.
15. Rogers, R. C., Capriotti, D. P., and Guy, R. W., "Experimental Supersonic Combustion Research at NASA Langley," AIAA 98-2506, June 1998.
16. Voland, R. T., et al., "Hyper-X Engine Design and Ground Test Program," AIAA 98-1532, April 1998.
17. Hunt, J. L. and Rausch, V. L., "Airbreathing Hypersonic Systems Focus at NASA Langley Research Center," AIAA 98-1641, April 1998.
18. Morgan, A. E., et al., "Preliminary Experiments in the Development of the Radiatively Driven Wind Tunnel," AIAA 98-2498, June 1998.